WFA Workshop on Coexistence

LTE-U Forum Way Forward on WFA Test Plan

Verizon, Ericsson, Samsung, Nokia, LGE, T-Mobile, Qualcomm

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Outline

- Brief reminder of LTE-U coexistence mechanisms
- On Wi-Fi spectrum sharing performance
- On Wi-Fi operating RSSI regime
  - RSSI measurements from Wi-Fi chipsets can be biased
  - Deployment recommendations from leading Wi-Fi suppliers and professional installers confirm need for higher RSSI
  - Measurements showing issues with Wi-Fi link at -80dBm
- Summary and Recommendations

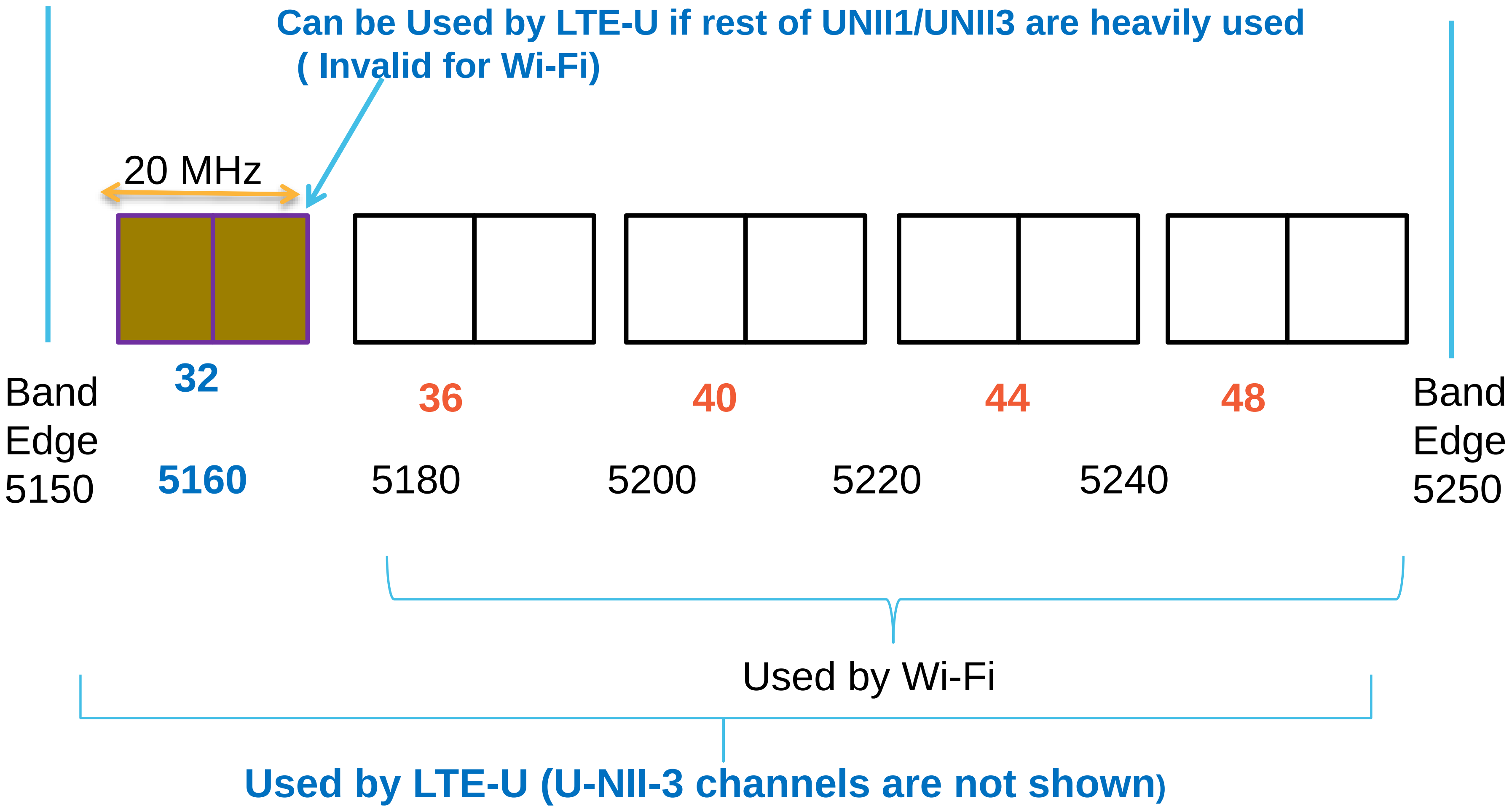
LTEu Coexistence Mechanisms

Coexistence Mechanisms in LTE-U

- Coexistence Mechanisms in LTE-U
  - 1) Channel Selection – Frequency-domain (U-NII-1, U-NII-3)
  - 2) Shared Channel – Time-domain
  - 3) Opportunistic Scell – Turn Scell OFF when not needed

- Real World
  - Channel selection suffices in most cases
  - Valid channel numbering for Wi-Fi, at 5 GHz, begins with channel 36
  - LTE-U optionally leverages channel 32 (U-NII-1), not currently a valid channel for Wi-Fi (see next slides)
    - Even in extremely congested Wi-Fi scenarios, where Wi-Fi uses all the supported channels in U-NII-1 (ch 36, 40, 44, 48) and U-NII-3, the channel selection algorithm in LTE-U can optionally select channel 32 (unused by Wi-Fi), avoiding interference to Wi-Fi

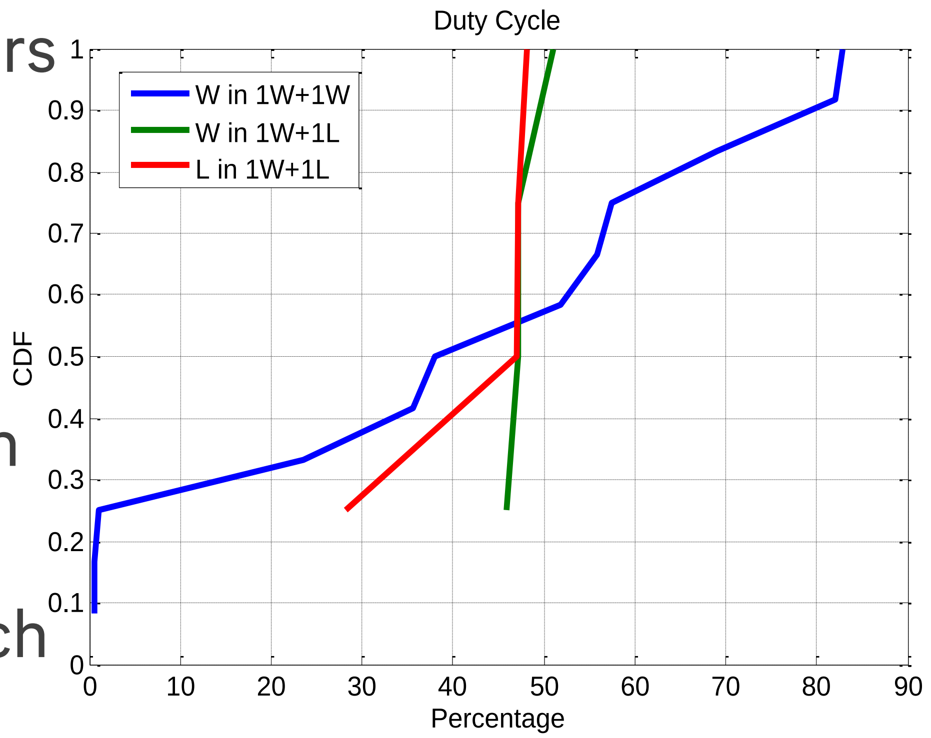
Current Valid Wi-Fi Channels for U-NII-1



On WiFi Sharing

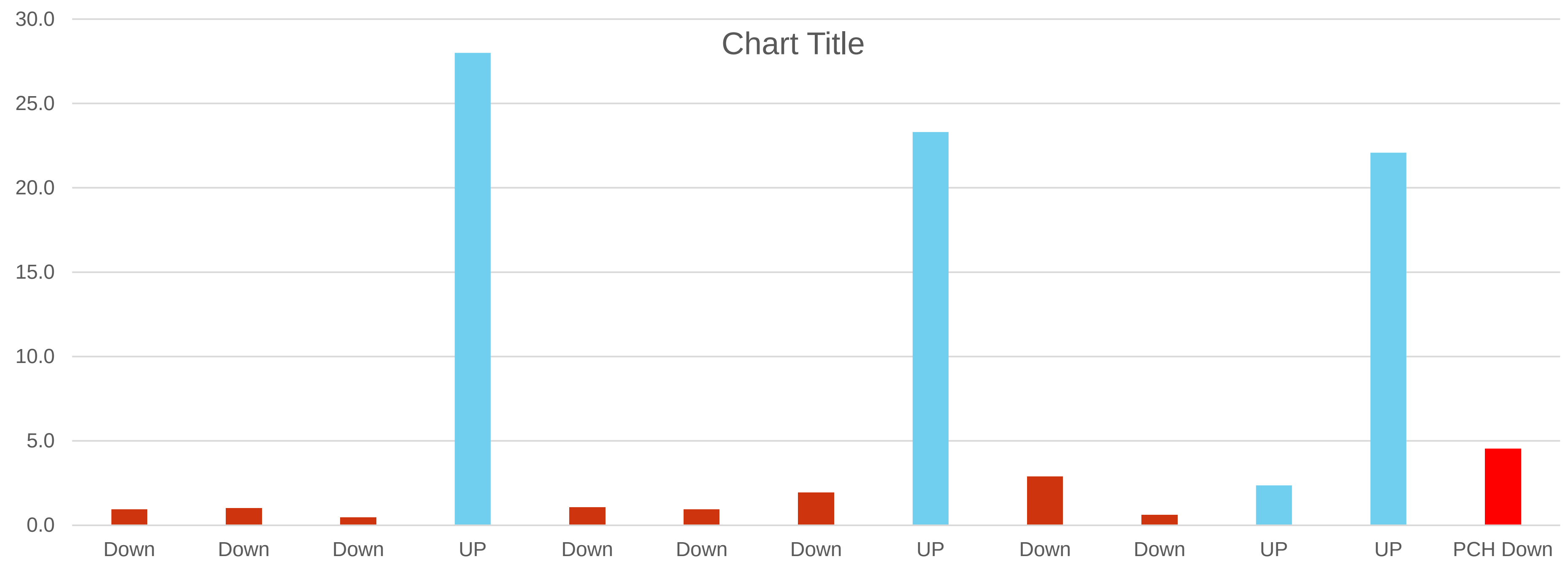
Wi-Fi/Wi-Fi Sharing Example (Screen Room)

- A set of 4 Wi-Fi APs, A,B,C,D from different vendors are considered
- All tests are above ED
- Each AP is connected to a STA
- In each test, two APs and associated STAs are run
  - Full buffer traffic
- Test metric is how fair the two APs share with each other
  - Ideally, they would share 50% each
- We repeat the test, replacing one of the WiFi APs with LTE-U



Observation: Wi-Fi APs do not share the medium equally, Unequal sharing is attributed to several factors, among which using different TxOP length (802.11 spec allows different TxOP duration)

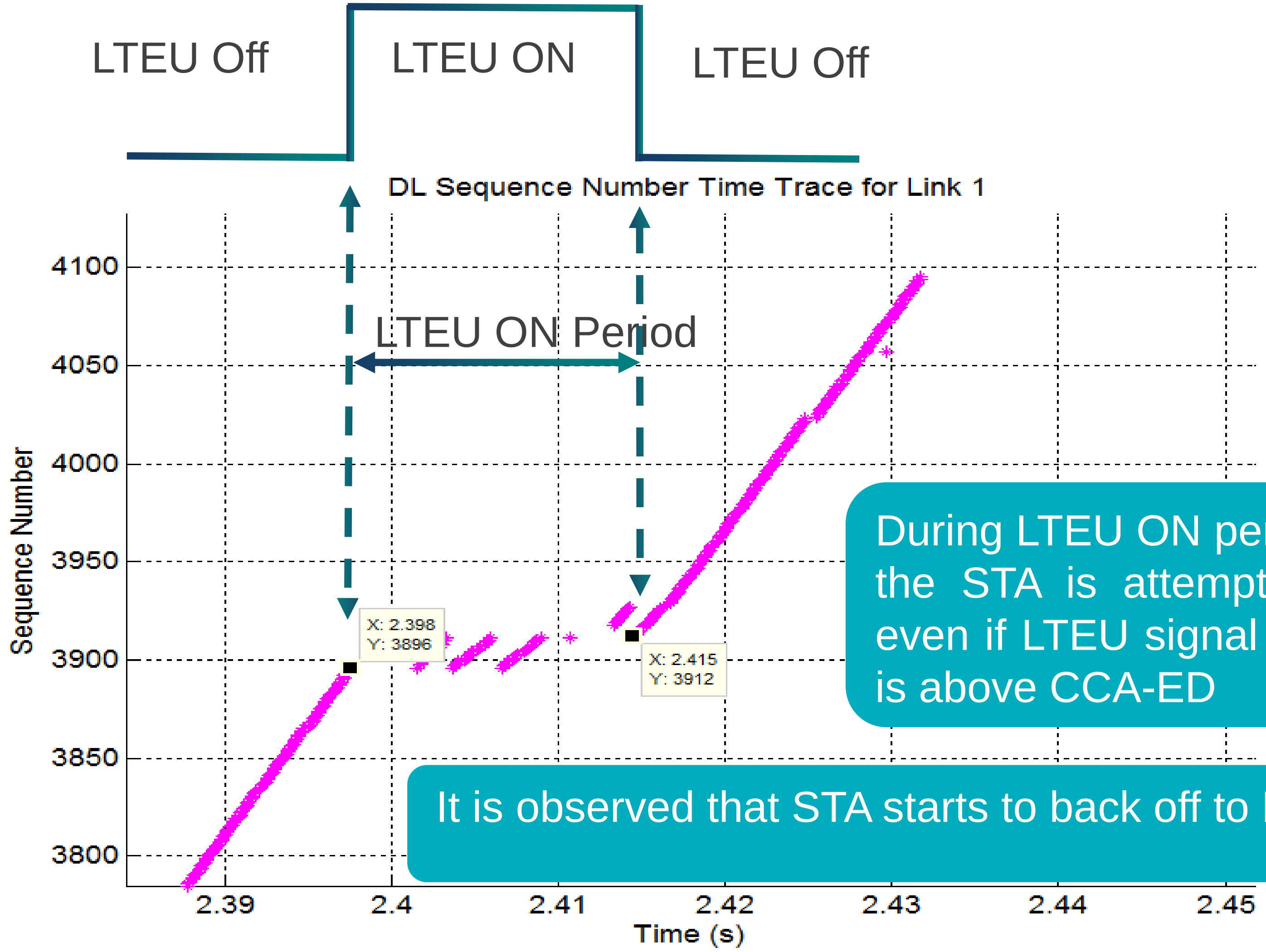
Multi Node WiFi Sharing with Mixed UL/DL Traffic—Above ED



Observation: Diverse TxOP durations used by the STAs and APs causing significant unfairness in UL/DL air time sharing

STA Backoff Behavior at -60 dBm

LTEU adapts its duty cycle to coexist with Wi-Fi, but Wi-Fi device is occupying the whole airtime, even above -62dBm



During LTEU ON period we can see the STA is attempting to transmit even if LTEU signal at STA location is above CCA-ED

It is observed that STA starts to back off to LTEU energy **at -55 dBm**

Below ED – SCH Results

- 802.11 spec only defined preamble detection for Wi-Fi primary channel
- In case of 802.11n/802.11ac where the BW can be > 20MHz (e.g. 40MHz, 80MHz, 160MHz)
  - 802.11 spec only requires preamble detection @-82dBm on the primary 20MHz channel, and energy detection at -62dBm on the secondary channel(s). 802.11ax increases the sensitivity for detecting secondary channels from -62dBm to -72dBm
- Therefore, Wi-Fi only protects other technologies above -62dBm, and for protects other Wi-Fi nodes using its secondary channel only above -72dBm

- AP Vendor **A is 40MHz**, and AP Vendor **B is 20MHz** sharing AP A secondary channel
- Although the RSSI is -62dBm, the Vendor A AP is not backing off to Vendor B AP, and significant collisions occur resulting in low throughput for both

Vendor A(40MHz)+Interferer(20MHz)	SNR 0 dB	
	Vendor A	Vendor B
W Baseline Thpt in Mbps	103.0	
W+W Thpt in Mbps	29.0	11.5

On WiFi Operating RSSI Regime

Background

- Several WFA submissions have presented low Wi-Fi Reported RSSI measurements as an argument to further reduce the ED threshold below -72 dBm
  - These measurements have been presented as true absolute signal strength numbers representing dBm

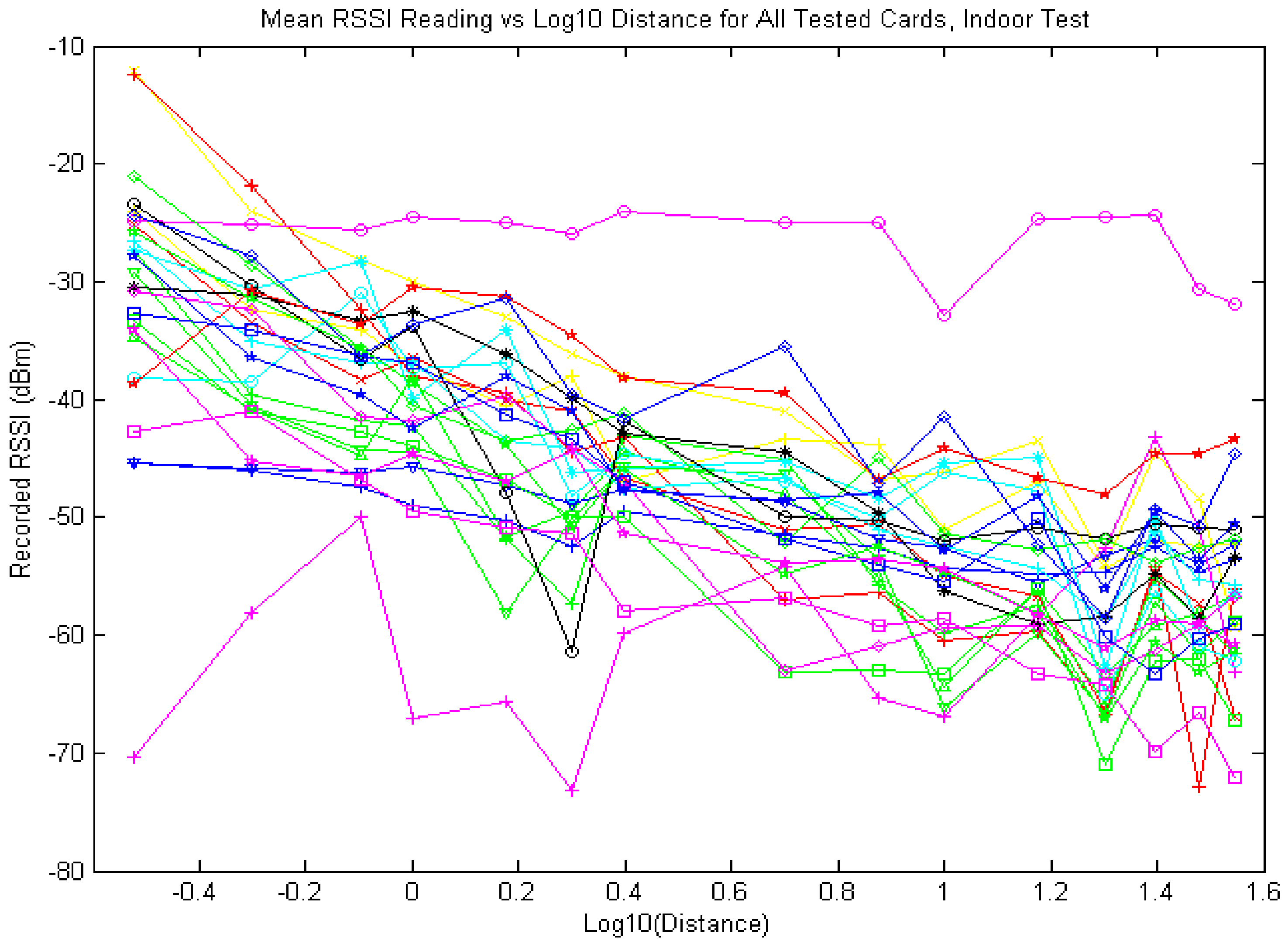
- Regardless that SINR is the right approach, Wi-Fi measurements are known to be relative indicators, rather than absolute numbers, as supported by **published papers**, the **IEEE 802.11 standard**, **enterprise documentation**, and **lab test results**
  - There is no fixed standard which Wi-Fi manufacturers are required to follow; thus, Wi-Fi RSSI measurements should only be considered as relative indicators, and cannot be used to justify changes to ED thresholds

Published Papers Conclude Wi-Fi RSSI Measurements are Relative

- Lui, et. al. in their 2011 IEEE paper "*Differences in RSSI Readings Made by Different Wi-Fi Chipsets: A Limitation of WLAN Localization*" characterized 17 different devices with various manufacturers, models, and chipsets
  - They found "big differences between the values reported."
  - In the indoor tests, differences of as much as 30 dB were observed in averaged RSSI, and in the outdoor test, the same order of differences was observed.

- Lui concludes with *"As there is no fixed standard which manufacturers are required to follow, signal strength indications are to be used for indication only and do not indicate the true absolute signal strength received."*

Differences in RSSI Readings Made by Different Wi-Fi Devices/Chipsets



Id	Manufacturer and Model	Chipset
	Diamond Digital A101	Envara WiND502
	Netgear WG111v2	Realtek (RTL8187L)
	Netgear WPN111	Atheros (AR5523A/AR2112A)
	Netgear WG111U	Atheros (AR5523A/AR5112A)
	D-Link DWA-140	Ralink RT2870
	D-Link DWL-122G	Ralink RT2570
	Netgear MA101	Atmel AT7650x
	Billion BiPAC3011G	Zydas (ZD1211)
	Belkin Play USB	Broadcom (BCM4323)
	HP2133 Mini Notebook	Broadcom (BCM4312)
	BenQ Joybook R55UV10 laptop	Intel Centrino 3945ABG
	HP Pavilion dv4000 laptop	Intel Centrino 2200BG
	HP Elitebook	Intel Wi-Fi Link 5300N
	Asus EEEPC 701	Atheros (AR5006UG)
	Nokia N95	Unknown
	HTC Dream	Texas Instruments WL1251B
	Roving Networks Wi-Fi Tag	Unknown

RSSI as Specified in the IEEE 802.11 Standard

- Absolute accuracy of the RSSI reading is not specified:

14.3.3.3 RXVECTOR RSSI

The RSSI is an optional parameter that has a value of 0 to RSSI Max. This parameter is a measure by the PHY of the energy observed at the antenna used to receive the current PPDU. RSSI shall be measured between the beginning of the SFD and the end of the PLCP HEC. RSSI is intended to be used in a relative manner. Absolute accuracy of the RSSI reading is not specified.

- RSSI is intended to be used in a relative manner:

18.2.3.3 RXVECTOR RSSI

The allowed values for the RSSI parameter are in the range from 0 to RSSI maximum. This parameter is a measure by the PHY of the energy observed at the antenna used to receive the current PPDU. RSSI shall be measured during the reception of the PLCP preamble. RSSI is intended to be used in a relative manner, and it shall be a monotonically increasing function of the received power.

- RSSI is implementation dependent:

RSSI	PMD_RSSI.indication	8 bits of RSSI (256 levels)	The RSSI is a measure of the RF energy received. Mapping of the RSSI values to actual received power is implementation dependent. See 19.9.5.11.

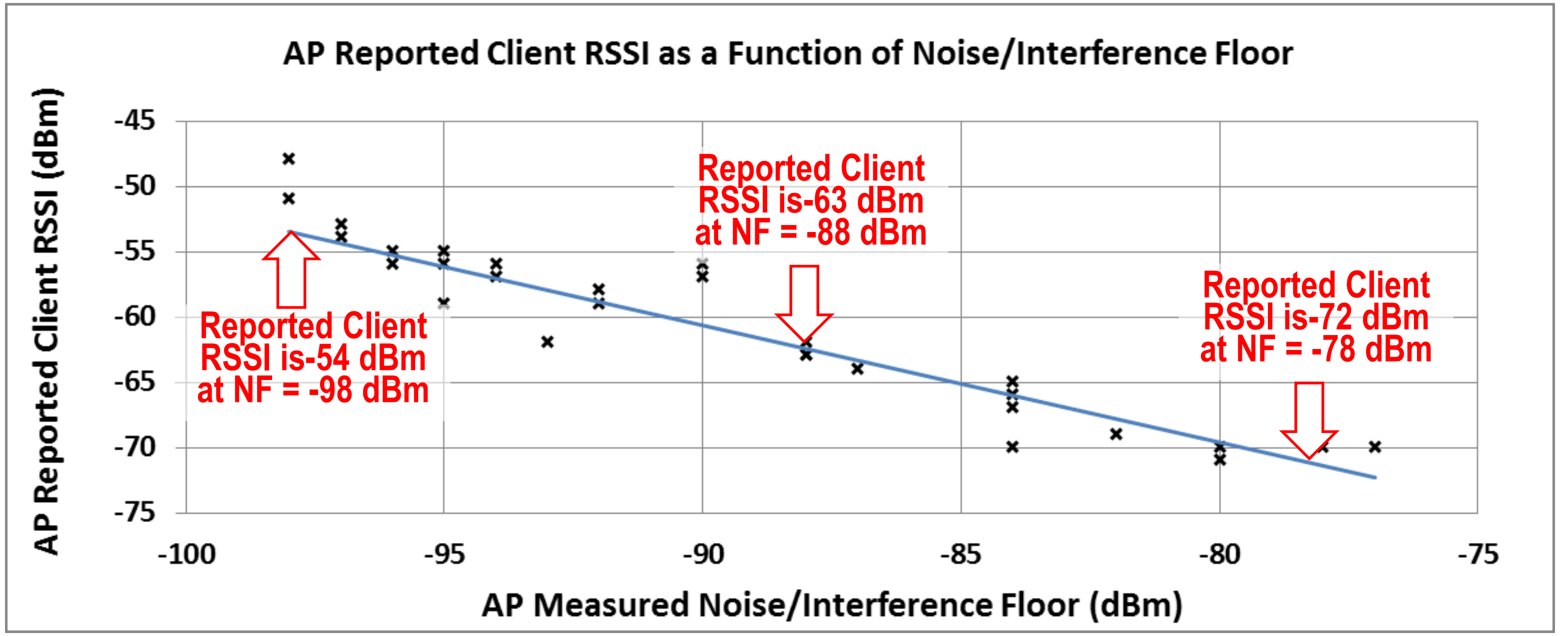
Lab Test Results: AP Reported Client RSSI

- Ericsson lab tested a Wi-Fi client and a Wi-Fi AP at a fixed distance. Gaussian noise was used to impact the Client SINR.
- Ericsson's lab measurements show that AP Reported Client RSSI was directly affected by the noise floor.
- ***Every 1 dB increase in AP measured noise floor caused the AP Reported Client RSSI to drop by 1 dB.***
- This follows AP SW which estimates RSSI as SINR + (-95) dBm.
  As SINR decreases 1 dB, Client Reported RSSI will also decrease 1 dB.

Agilent E4438C VSG used to inject Gaussian Noise

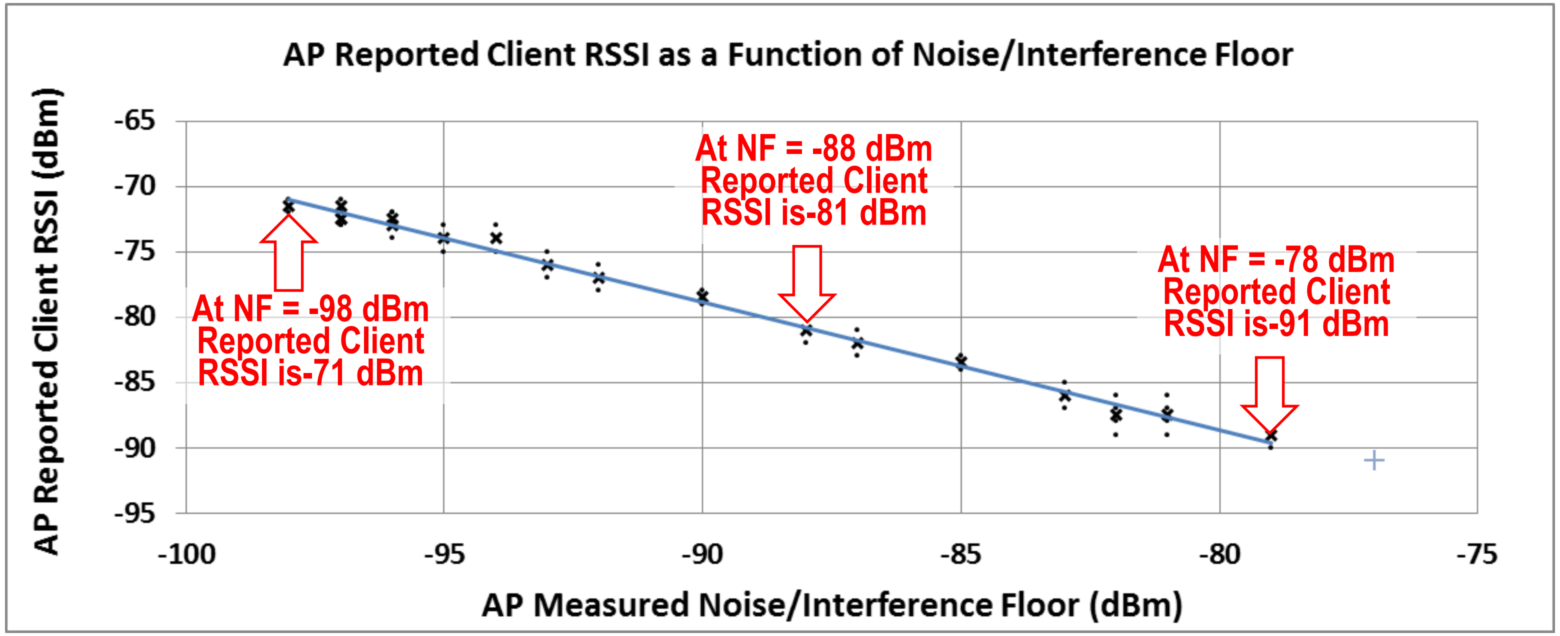
AP Reported Client RSSI (Client @ -54 dBm)

- The first test below was conducted in the Ericsson lab.
  - At a noise floor of -98 dBm, AP reported Client RSSI was -54 dBm.
  - At a noise floor of -88 dBm, AP reported Client RSSI was -63 dBm.
  - At a noise floor of -78 dBm, AP reported Client RSSI was -72 dBm.
- The AP Reported Client RSSI is calculated from SINR.



AP Reported Client RSSI (Client @ -71 dBm)

- The second test below was conducted in the Ericsson lab.
  - At a noise floor of -98 dBm, AP reported Client RSSI was -71 dBm.
  - At a noise floor of -88 dBm, AP reported Client RSSI was -81 dBm.
  - At a noise floor of -78 dBm, AP reported Client RSSI was -91 dBm.
- The AP Reported Client RSSI is calculated from SINR.



Conclusions – RSSI Fidelity

- Wi-Fi Reported Client RSSI measurements cannot be used as absolute values, as they are only relative indicators
- This is supported by papers, the 802.11 standard, Wi-Fi AP manufacturer documentation, and Ericsson lab test results
- Wi-Fi Reported Client RSSI measurements based on SINR are used to indicate signal quality, and not absolute dBm
- Client RSSI reporting errors increase with interference
- Urban outdoor and high capacity venues such as stadiums where interference levels are high, have the greatest reporting errors showing Clients as much as 20 dB lower than the true signal dBm levels

So What Does WiFi Deployment Guidelines say on RSSI Levels?

AP SPACING RECOMMENDATIONS

- Vendor A: 25 feet AP-to-Client:

How far is the client from the access point?

The next thing to consider is distance. How far is the client from the AP? 802.11ac introduces 256 QAM, and it is a more complex modulation so that modulation is harder to maintain over distance. If you want to consistently show 256 QAM, which equates to m8 and m9, we recommend keeping the client within 25'. Beyond 25', you will still see m8/m9, but not consistently.

- Vendor B: 20-30 feet AP-to-Client (40-60' between APs)

Recommendations for AP Placements

AP placement recommendations for an enterprise network, which needs to support high-performing 802.11ac network along with real-time voice and video applications, are as follows:

- Distance between two APs should be approximately 40 to 60 feet.
- Minimum RSSI should be -65 dBm throughout the coverage area.
- SNR should be greater than 25 dB.
- APs should be deployed in a honeycomb pattern as shown in the following diagram. This pattern ensures that distance is normalized along all directions to have the best coverage.

RF Recommendations for Deployment (Retail and Enterprise Applications)

- Vendor C recommendations for enterprise Wi-Fi:
  - "AP placement recommendations for an enterprise network, which needs to support high-performing 802.11ac network along with real-time voice and video applications, are as follows:
    - Distance between two APs should be approximately 40 to 60 feet.
    - Minimum RSSI should be **-65 dBm** throughout the coverage area…."

- Vendor D recommendations for retail applications
  - " For data services, design the WLAN so that the communicating wireless devices have a minimum RSSI (received signal strength indicator) of **-70 dBm** and an SNR of 20 dB or higher. For a WLAN supporting voice and video, implement a design in which the RSSI is at least **-67** dBm with an SNR of 23 dB or higher."
  - " Ideally, a client should be able to detect a signal of -70 dBm or better from one AP and another signal of -75 dBm or better from one or more others."

RF Recommendations for Deployment (Retail and Enterprise Applications) – Cont'd

- Vendor E recommendations for enterprise Wi-Fi
  - "Most application specific coverage guidelines describe the signal level or coverage at the cell edge required for good operation as a design recommendation. This is generally a negative RSSI value like **-67 dBm**. It's important to understand that this number assumes good signal to noise ratio of 25 dB with a noise floor of -92 dBm. If the noise floor is higher than -92 dBm then -67 dBm may not be enough signal to support the minimum data rates required for the application to perform it's function
  - "For **location-aware services**, deploying a network to a specification on -67 dBm is fine – however what matters to location-aware applications is how the network hears the client – not how the client hears network. For Location-Aware we need to hear the client at three AP's or more at a level of >= -75 dBm for it to be part of the calculation. (-72 is the recommended design minimum)"

RF Recommendations for Deployment (Retail and Enterprise Applications) – Cont'd

- Vendor F recommendations for enterprise Wi-Fi
  - *"The AP coverage should be planned for a minimum of -65 dBm as observed by the most frequently used client device for voice calls. The channel planning should be done in a way such that there is substantial gap between the same channel cells - It is recommended that there is a ~20dB gap between the cell boundaries. In cases where no 'frequently used' client is defined, the coverage should be planned for a worst case scenario using a device with known poor roaming performance but with a likelihood of being used in the network."*

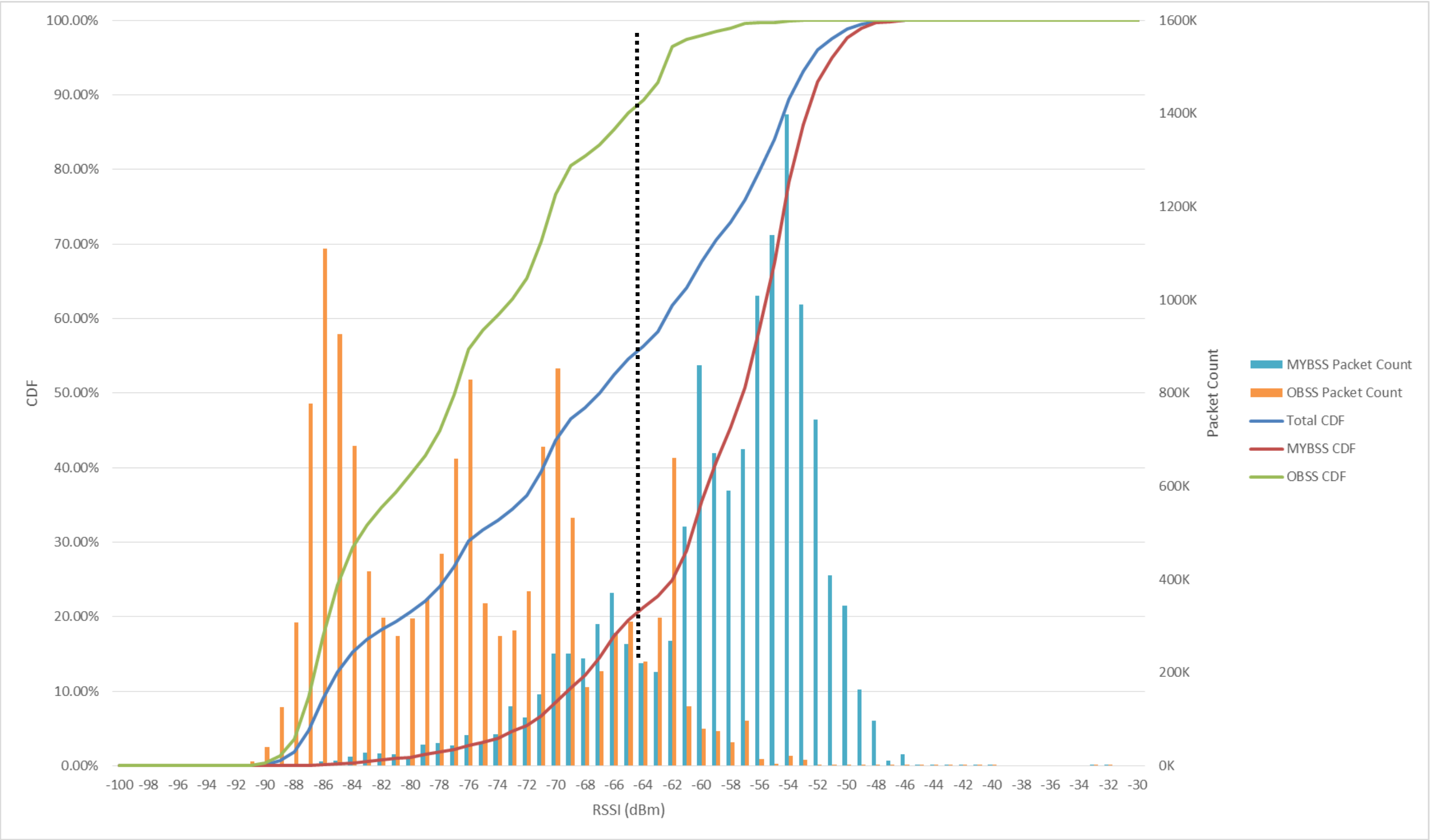
- iOS roaming recommendations https://support.apple.com/en-us/HT203068
  - *"iOS clients monitor and maintain the current BSSID's connection until the RSSI crosses the **-70 dBm** threshold. Once crossed, iOS initiates a scan to find roam candidate BSSIDs for the current ESSID."*

Interference and SINR Distribution from HPE Field Measurements

- HPE presented field measurements from indoor enterprise and large stadium
- The measurements included both MyBSS (desired signal) and OBSS (interference) RSSI levels – **this is the right approach**
  - Previous field measurements from CL, Boingo, E/// only considered MyBSS RSSI distribution
- The results from HPE are useful as it can shed some light SINR distribution to consider in the test plans
  - Especially that RSSI measurements can be biased as illustrated before
- Results show that SINR distribution is in the range of **10-20 dB (see next slide)**
- HPE agreed with the high RSSI observation in myBSS and recommended testing at -77dBm as mandatory

Recommendation: SINR distribution in the WFA TP should be selected in the 10-20dB range. Some of current WFA test cases have SINR in range of neg30dB which is contradictory with field

Original: Measurement Results: Bay Area Enterprise (All Channels)



Channels: 36+, 44+, 52+, 108+ and 157+

Duration: ~15 min on each channel

Noise floor: -92dBm

MyBSSID Count: 15

OBSSID Count: 199

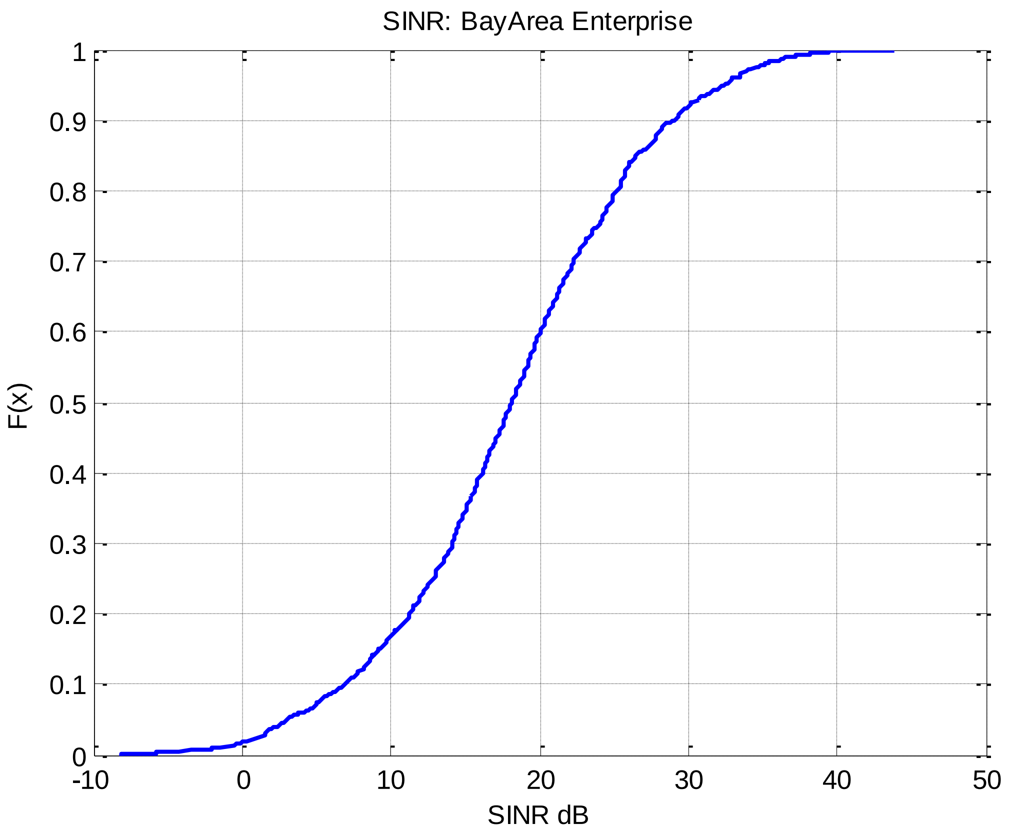
My STA Count: 378

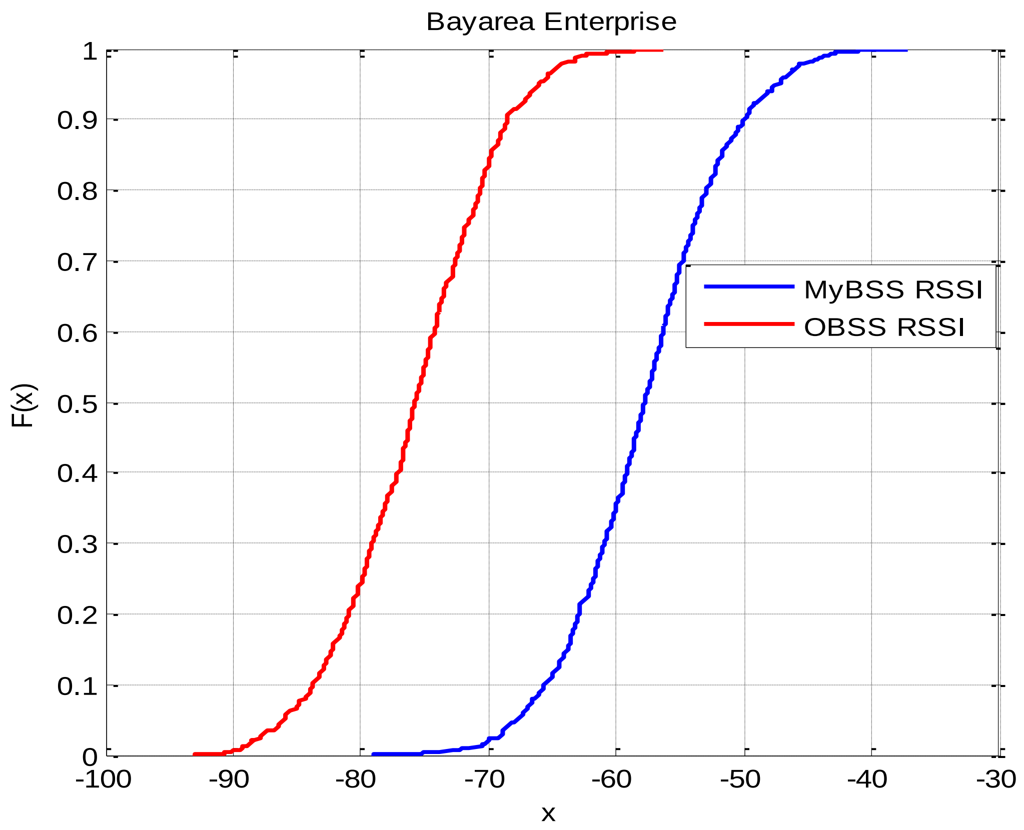
OBSS STA Count: 1157

Packets Captured:
- MyBSS: 12,839,489
- OBSS: 13,631,534
- Total: 26,471,023

Traffic below -72dBm:
- **MyBSS: 5.4%**
- **OBSS: 65%**
- MyBSS+OBSS: 36%

Empirical Analysis





Response to WFA Staff Slides on NAL

- There are several weakness points in the presentation from WFA staff on what is called NAL (we recommend using ED level) which can be summarized into two categories
- *Category 1*: technical inaccuracies
  - **The analysis lacks using any sound pathloss model that can reflect indoor or outdoor deployments**
  - **The analysis ignores field measurement results reflecting interference and SINR distribution as presented by HPE**
  - The analysis is using conducted measurements and not taking fading margin into account
  - The experiment is conducted with a signal generator with fixed duty cycle which is not representing LTE-U which utilizes adaptive duty cycle – although LTE-U MTPs have been provided by QC
  - The analysis makes certain assumptions on Wi-Fi sensitivities going to very low RSSI without actual measurements
- *Category 2*: lack of Wi-Fi baseline performance
  - **There is no Wi-Fi+Wi-Fi baseline coexistence results to backup the -94dBm CCA protection recommended by WFA Staff**
  - The analysis leading to -94dBm is inconsistent with exhaustive testing done on Wi-Fi/Wi-Fi sharing by different companies and during WFA validation testing showing poor sharing between Wi-Fi devices (even same vendor), besides Wi-Fi going to sleep mode or starting roaming at signal levels below -75dBm

Conclusion – Best Practices

- Sound engineering practices from Wi-Fi equipment vendors recommend a minimum signal level that ranges between -65 dBm to -72 dBm, for retail and enterprise applications

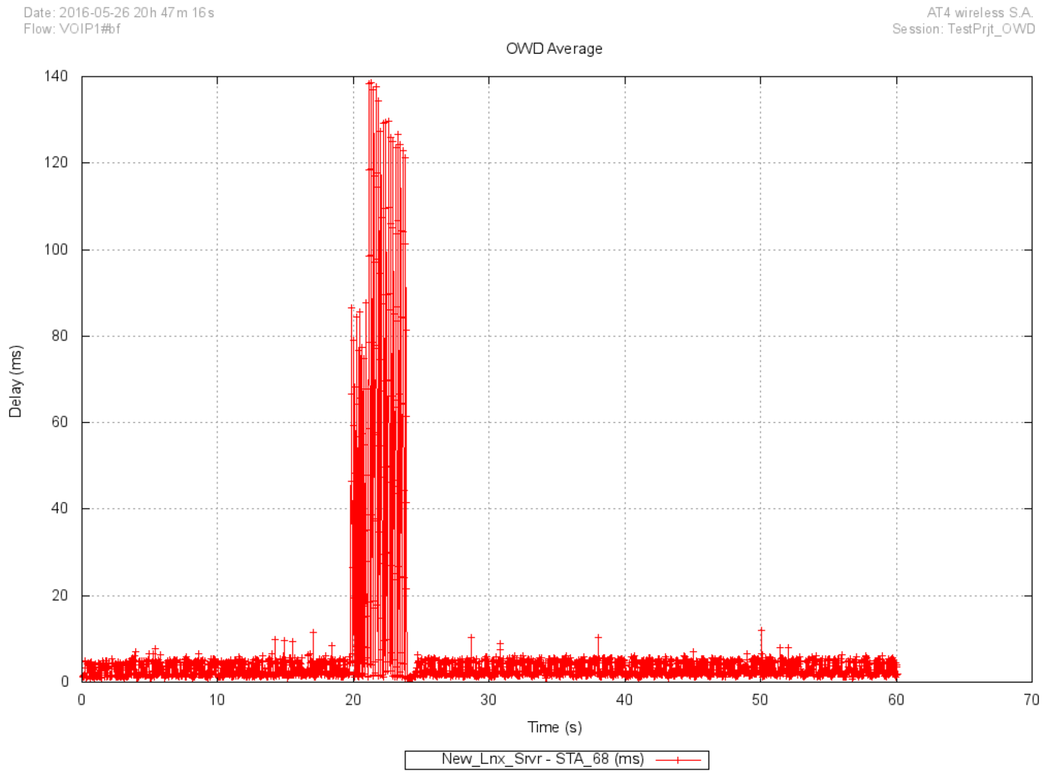
- Both guidelines and measurements are showing 20+dB SINR, something completely ignored in NAL analysis by staff and can significantly change the picture

WiFi Unpredictable behavior at low RSSI

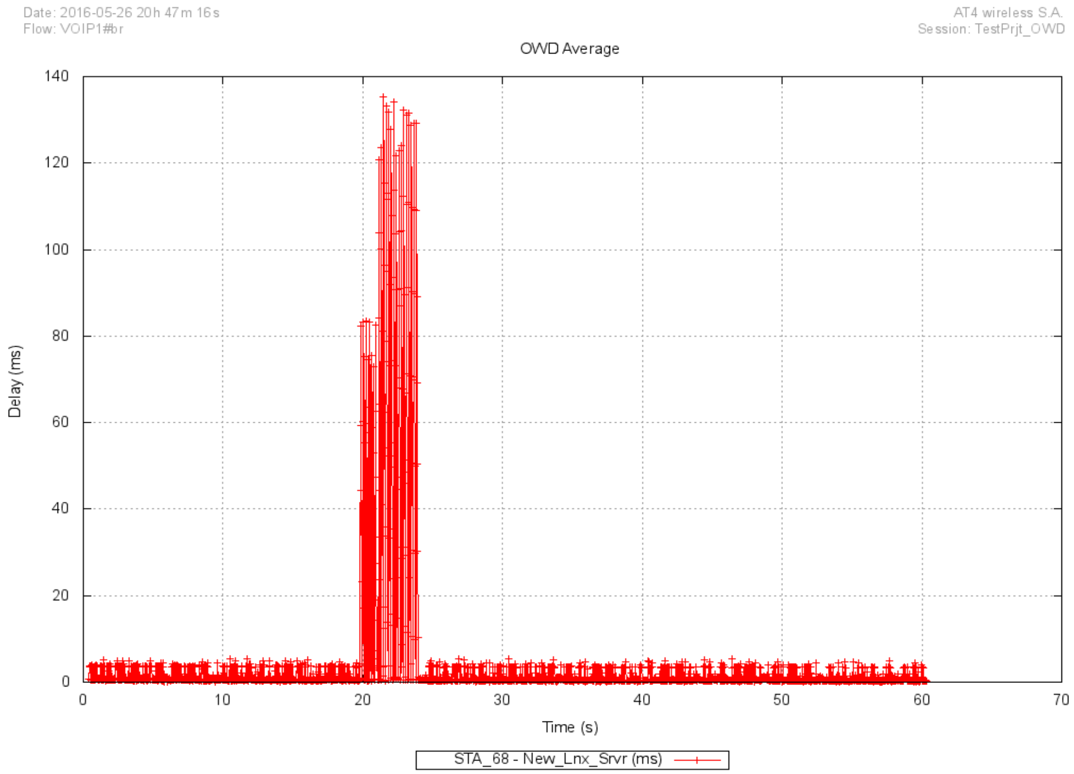
Bi-directional VoIP flow @ -80dBm – Delay Issues

- 2 out of 5 iterations exhibited high One Way Delay (OWD) values

Downlink OWD time plot



Uplink OWD time plot



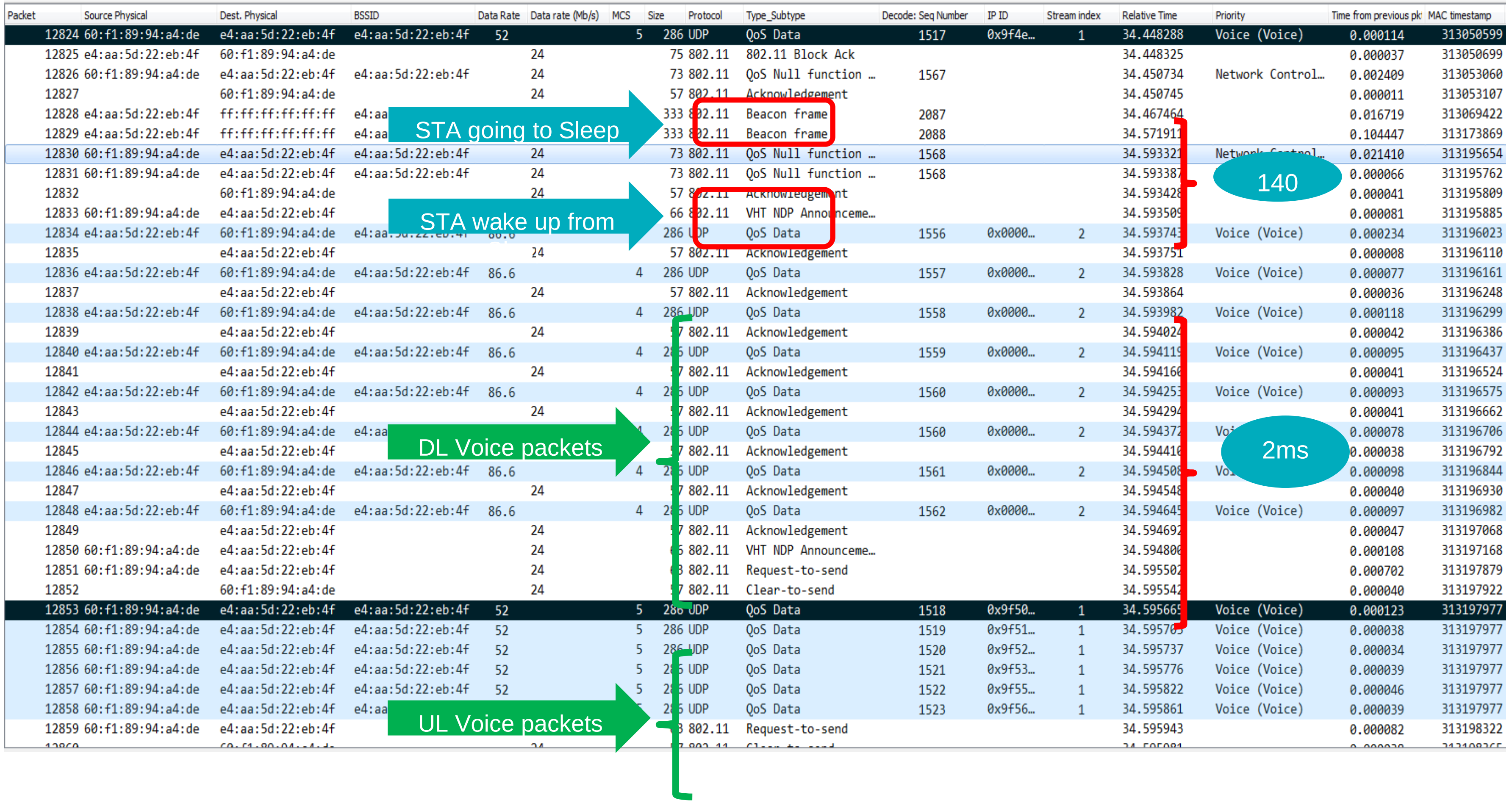
- DL & UL One Way Delay peaks at the same time for same duration

Similar behavior seen on several popular products

STA's Power Save mode

- In the middle of call, STA goes to power save mode for 140ms
  - Most probable reason: **Wi-Fi scanning**

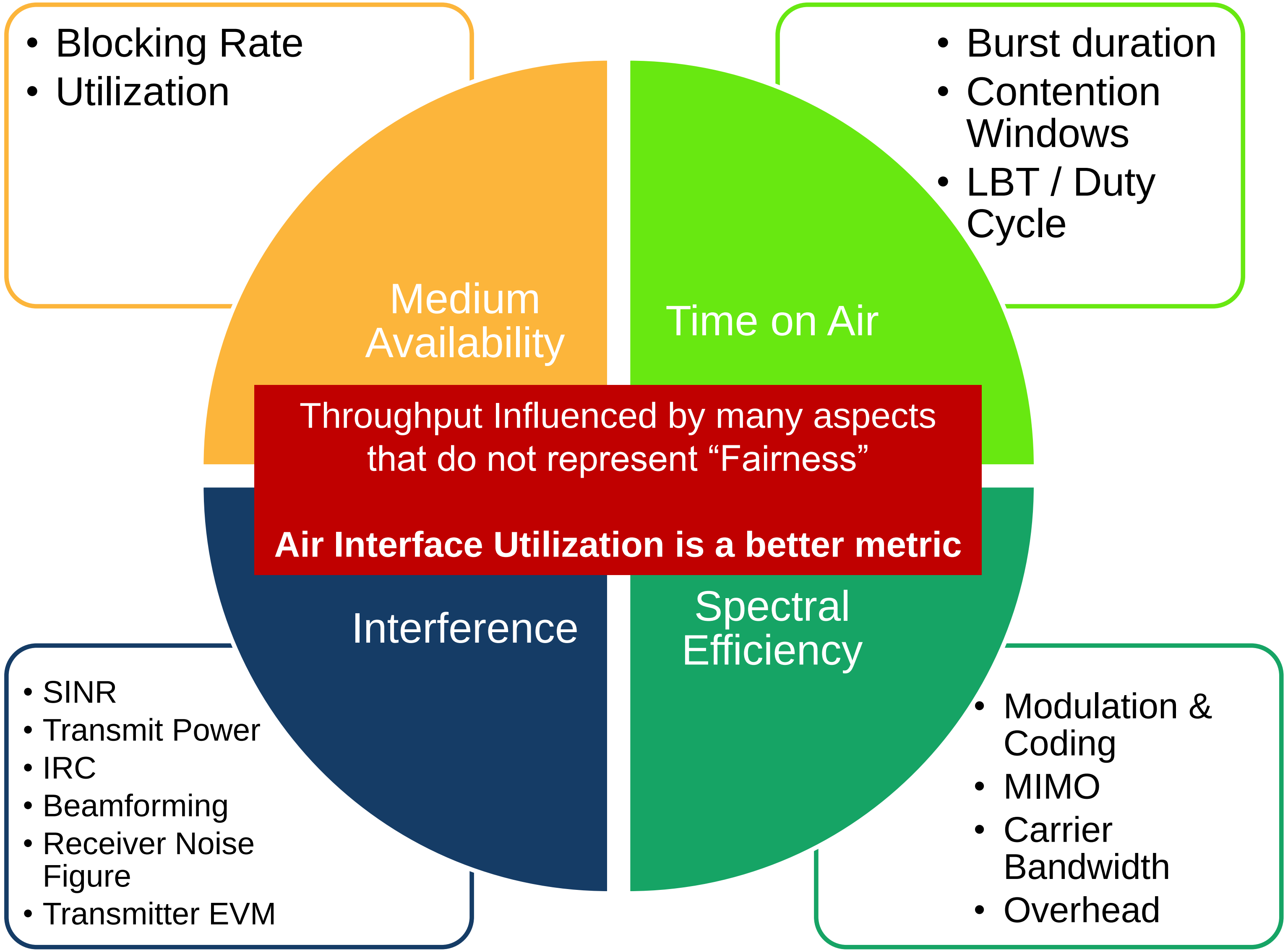
> • Wi-Fi links can have unpredictable performance at -80dBm, which aligns with deployment recommendation for Wi-Fi to be above -70dBm or higher



Packet	Source Physical	Dest. Physical	BSSID	Data Rate	Data rate (Mb/s)	MCS	Size	Protocol	Type_Subtype	Decode: Seq Number	IP ID	Stream index	Relative Time	Priority	Time from previous pk	MAC timestamp
12824	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	e4:aa:5d:22:eb:4f	52		5	286	UDP	QoS Data	1517	0x9f4e…	1	34.448288	Voice (Voice)	0.000114	313050599
12825	e4:aa:5d:22:eb:4f	60:f1:89:94:a4:de			24		75	802.11	802.11 Block Ack				34.448325		0.000037	313050699
12826	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	e4:aa:5d:22:eb:4f		24		73	802.11	QoS Null function …	1567			34.450734	Network Control…	0.002409	313053060
12827		60:f1:89:94:a4:de			24		57	802.11	Acknowledgement				34.450745		0.000011	313053107
12828	e4:aa:5d:22:eb:4f	ff:ff:ff:ff:ff:ff	e4:aa				333	802.11	Beacon frame	2087			34.467464		0.016719	313069422
12829	e4:aa:5d:22:eb:4f	ff:ff:ff:ff:ff:ff	e4:aa				333	802.11	Beacon frame	2088			34.571911		0.104447	313173869
12830	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	e4:aa:5d:22:eb:4f		24		73	802.11	QoS Null function …	1568			34.593321	Network Control…	0.021410	313195654
12831	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	e4:aa:5d:22:eb:4f		24		73	802.11	QoS Null function …	1568			34.593387		0.000066	313195762
12832		60:f1:89:94:a4:de			24		57	802.11	Acknowledgement				34.593428		0.000041	313195809
12833	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f			24		66	802.11	VHT NDP Announceme…				34.593509		0.000081	313195885
12834	e4:aa:5d:22:eb:4f	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	86.6			286	UDP	QoS Data	1556	0x0000…	2	34.593743	Voice (Voice)	0.000234	313196023
12835		e4:aa:5d:22:eb:4f			24		57	802.11	Acknowledgement				34.593751		0.000008	313196110
12836	e4:aa:5d:22:eb:4f	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	86.6		4	286	UDP	QoS Data	1557	0x0000…	2	34.593828	Voice (Voice)	0.000077	313196161
12837		e4:aa:5d:22:eb:4f			24		57	802.11	Acknowledgement				34.593864		0.000036	313196248
12838	e4:aa:5d:22:eb:4f	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	86.6		4	286	UDP	QoS Data	1558	0x0000…	2	34.593982	Voice (Voice)	0.000118	313196299
12839		e4:aa:5d:22:eb:4f			24		[illegible]	802.11	Acknowledgement				34.594024		0.000042	313196386
12840	e4:aa:5d:22:eb:4f	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	86.6		4	[illegible]	UDP	QoS Data	1559	0x0000…	2	34.594119	Voice (Voice)	0.000095	313196437
12841		e4:aa:5d:22:eb:4f			24		[illegible]	802.11	Acknowledgement				34.594166		0.000041	313196524
12842	e4:aa:5d:22:eb:4f	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	86.6		4	[illegible]	UDP	QoS Data	1560	0x0000…	2	34.594253	Voice (Voice)	0.000093	313196575
12843		e4:aa:5d:22:eb:4f			24		[illegible]	802.11	Acknowledgement				34.594294		0.000041	313196662
12844	e4:aa:5d:22:eb:4f	60:f1:89:94:a4:de	e4:aa	[illegible]		[illegible]	[illegible]	UDP	QoS Data	1560	0x0000…	2	34.594372	Vo	0.000078	313196706
12845		e4:aa:5d:22:eb:4f			24		[illegible]	802.11	Acknowledgement				34.594416		0.000038	313196792
12846	e4:aa:5d:22:eb:4f	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	86.6		4	[illegible]	UDP	QoS Data	1561	0x0000…	2	34.594508	Vo	0.000098	313196844
12847		e4:aa:5d:22:eb:4f			24		[illegible]	802.11	Acknowledgement				34.594548		0.000040	313196930
12848	e4:aa:5d:22:eb:4f	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	86.6		4	[illegible]	UDP	QoS Data	1562	0x0000…	2	34.594645	Voice (Voice)	0.000097	313196982
12849		e4:aa:5d:22:eb:4f			24		[illegible]	802.11	Acknowledgement				34.594692		0.000047	313197068
12850	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f			24		[illegible]	802.11	VHT NDP Announceme…				34.594806		0.000108	313197168
12851	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f			24		[illegible]	802.11	Request-to-send				34.595502		0.000702	313197879
12852		60:f1:89:94:a4:de			24		[illegible]	802.11	Clear-to-send				34.595542		0.000040	313197922
12853	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	e4:aa:5d:22:eb:4f	52		5	286	UDP	QoS Data	1518	0x9f50…	1	34.595665	Voice (Voice)	0.000123	313197977
12854	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	e4:aa:5d:22:eb:4f	52		5	286	UDP	QoS Data	1519	0x9f51…	1	34.595703	Voice (Voice)	0.000038	313197977
12855	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	e4:aa:5d:22:eb:4f	52		5	286	UDP	QoS Data	1520	0x9f52…	1	34.595737	Voice (Voice)	0.000034	313197977
12856	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	e4:aa:5d:22:eb:4f	52		5	[illegible]	UDP	QoS Data	1521	0x9f53…	1	34.595776	Voice (Voice)	0.000039	313197977
12857	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	e4:aa:5d:22:eb:4f	52		5	[illegible]	UDP	QoS Data	1522	0x9f55…	1	34.595822	Voice (Voice)	0.000046	313197977
12858	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f	e4:aa	[illegible]		[illegible]	[illegible]	UDP	QoS Data	1523	0x9f56…	1	34.595861	Voice (Voice)	0.000039	313197977
12859	60:f1:89:94:a4:de	e4:aa:5d:22:eb:4f					[illegible]	802.11	Request-to-send				34.595943		0.000082	313198322
[illegible]		[illegible]			[illegible]		[illegible]	[illegible]	[illegible]				[illegible]		[illegible]	[illegible]

Additional comments on other test cases

On Throughput Influencers



In-Device Coexistence Testing

- In-device coexistence is not unique to LTE-U/Wi-Fi, as the problem occurs in other scenarios
  - Wi-Fi/BT
  - LTE in B40/B7 and Wi-Fi
- In-device coexistence is out of scope of the WFA test plan which is defining sharing with other existing Wi-Fi devices
- In-device coexistence solutions were introduced in Rel-11 to handle multi-radio coexistence problems
- If concurrency is required by operators, UE can solve IDC problems internally through proprietary implementation, or indicate IDC problem to eNB which can utilize any of the solutions introduced in Rel-11
  - Currently implemented and commercialized for the problems above

Summary and Recommendations

- The general principle for test development so far in the group is that there should not be any requirement for LTE-U nodes to implement Wi-Fi transceiver module in their device for the sole purpose of coexistence – this has been widely ignored in TP and staff recommendations
- RSSI measurements by Wi-Fi devices cannot be used as absolute values since the measurements can be biased with interference level
- Sound engineering practices from Wi-Fi equipment vendors recommend a minimum signal level that ranges between -65 dBm to -72 dBm & SINR of 20+dB for retail and enterprise applications
  - This is further confirmed from observing that Wi-Fi devices (STAs) typically start scanning other channels and may go into sleep mode for RSSI levels below -75dBm
  - Wi-Fi field measurements show that SINR range is typically 10-20dB

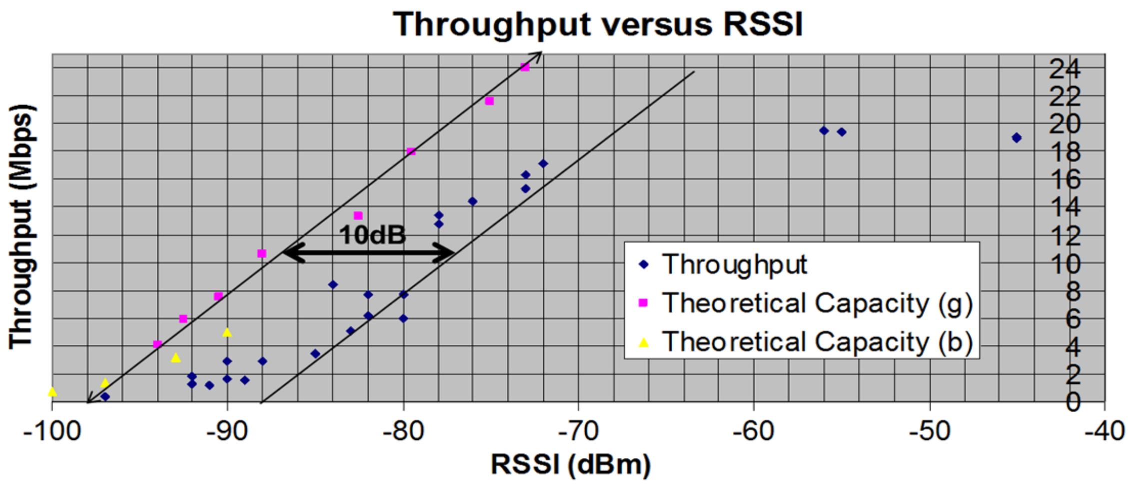
- Adopt -72dBm as mandatory ED level and below -72dBm as optional
  - Wi-Fi backs off to other technologies and to Wi-Fi on its secondary channels above -62dBm
  - Some Wi-Fi implementation even does not backoff at -62dBm
- In-Device coexistence test should be removed from the test plan as it is clearly out of scope

Thank you

Back up

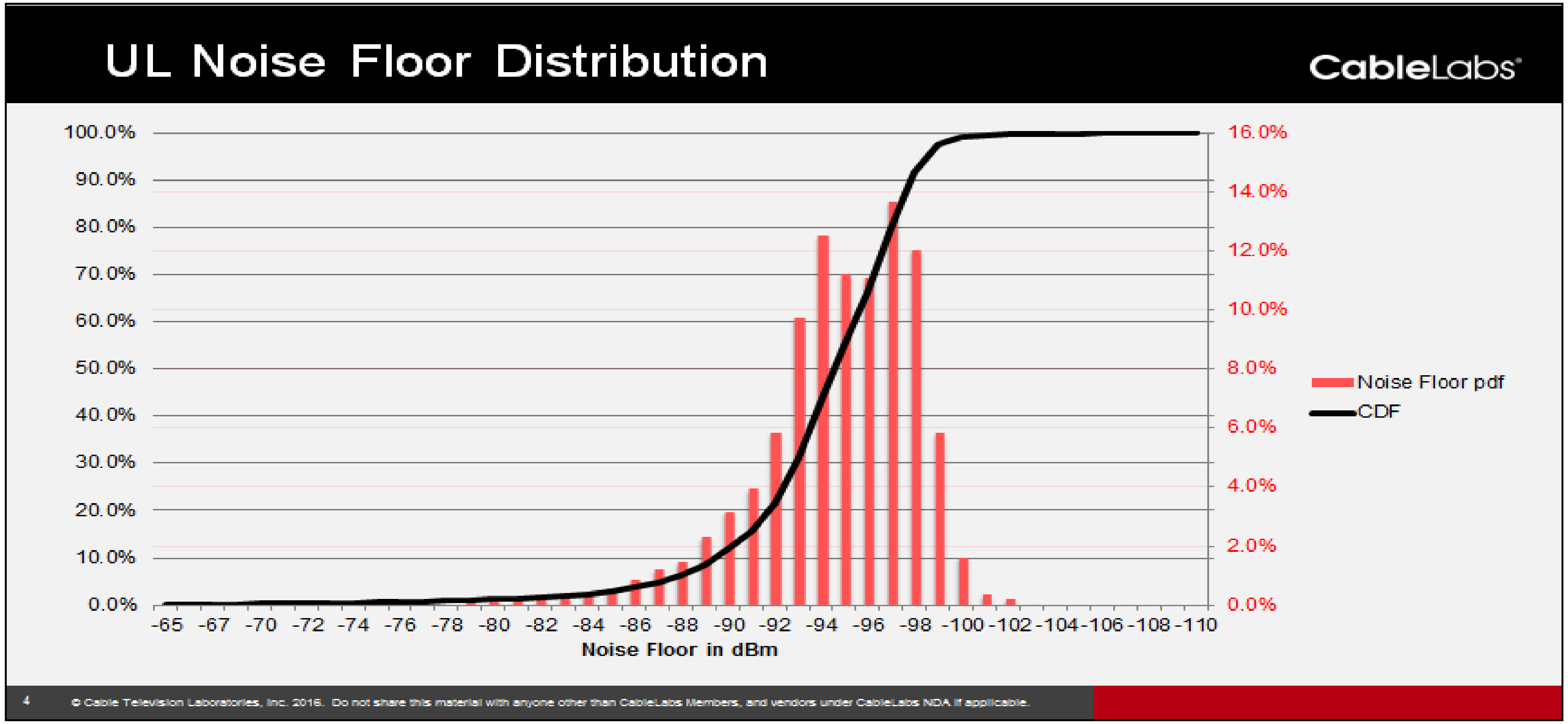
Outline

- CableLabs presented compiled data consisting of 1 million RSSI samples from over 13,000 outdoor APs. These RSSI samples varied from -52 dBm to -96 dBm, and were stated as being absolute values.
- It has been explained that this AP data is not absolute, but is a relative measurement of SINR.
- Moreover, the presented "absolute RSSI values" is not theoretically possible, as it does not account for fade margin. The best 5 GHz AP, running mcs0, with a receive sensitivity of -96 dBm, can only recover to -88 dBm over the air.   This is well understood by RF engineers.



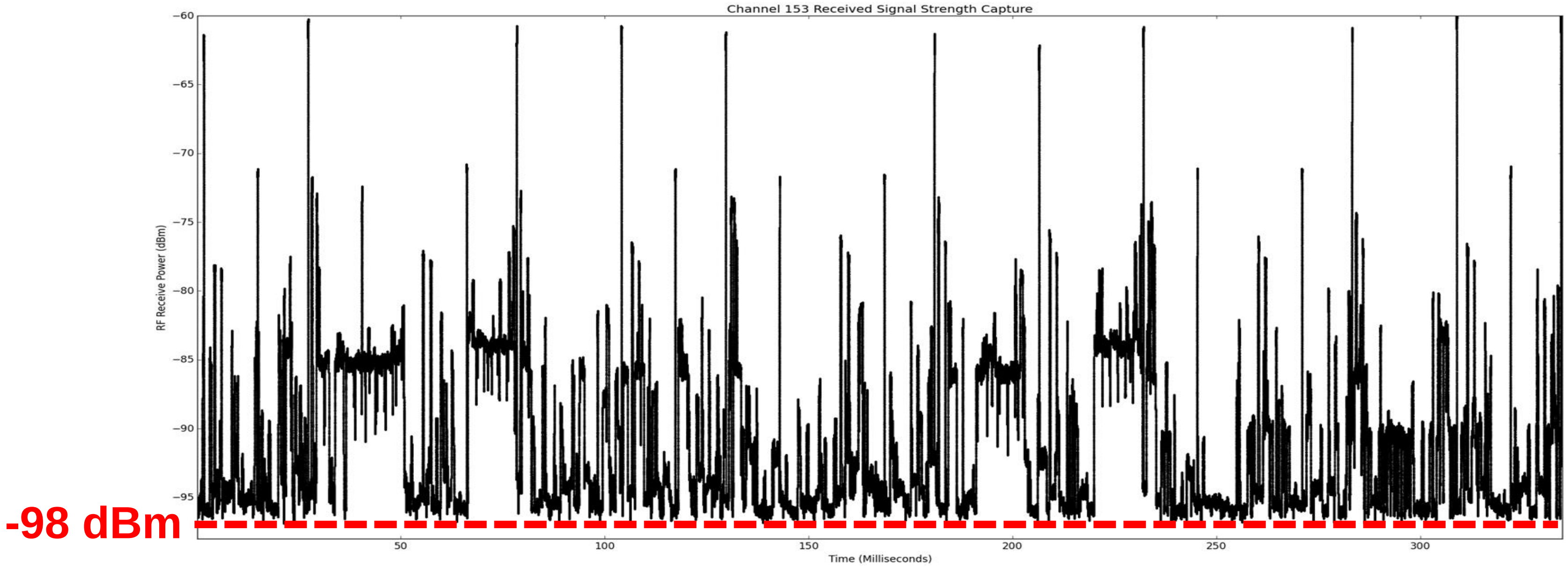
Cable Labs UL Noise Floor (NF) Data

- The good news is that CableLabs provided the UL NF Distribution of -84 dBm to -101 dBm – the theoretical 20 MHz channel limit
- The 50th percential was -94.5 dBm, indicating 6.5 dB average, and 17 dB maximum, noise floor interference increase



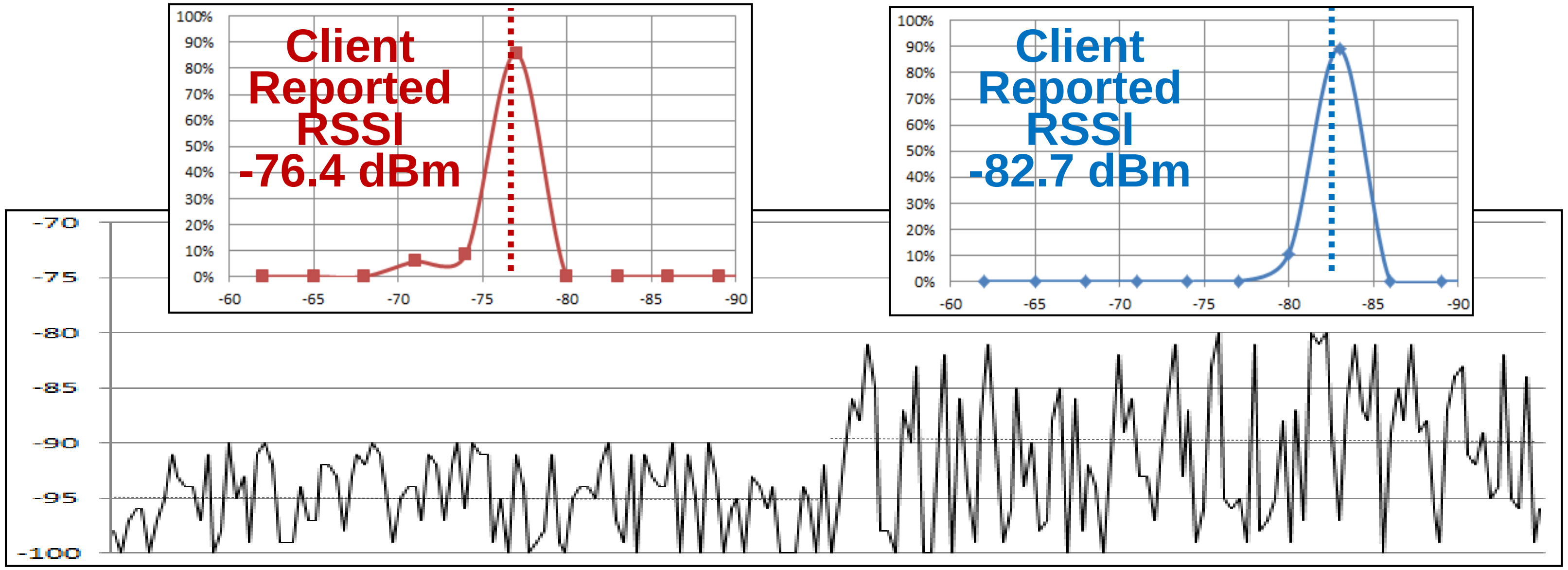
What Does UL Noise Floor (NF) Report?

- UL NF is used to re-baseline the -101 dBm thermal NF
- UL NF is a measure of the lowest signal level detected over a 3-minute interval, and is used by the receiver to set AGC levels
- The plot below is a spectrum analyzer capture of channel 153 in our Ericsson lab.   The environment is relatively clean, with a noise floor of -98 dBm, and most interference below -85 dBm.



Effect of Interference on Client Reported RSSI

- The lab plots below shows the effect of noise interference on Client Reported RSSI, initially seen (red) as -76.4 dBm.
- A 10 dB interference noise increase causes the Client Reported RSSI (blue) to be seen as -82.7 dBm (6.3 dB).
- Each test ran for over 200,000 collected sample points.

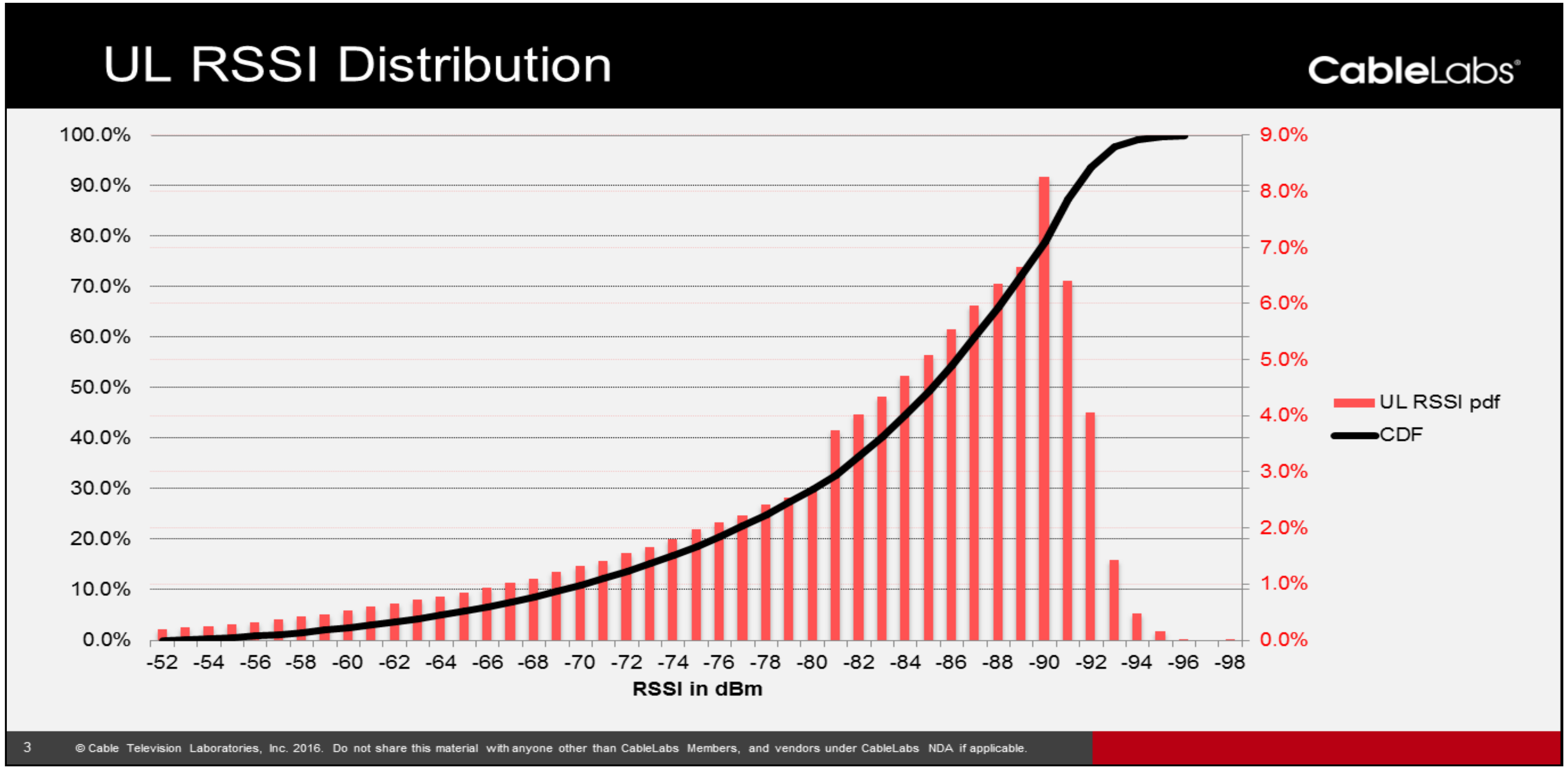


MEAN INTERFERENCE -95 dBm

MEAN INTERFERNCE -90 dBm

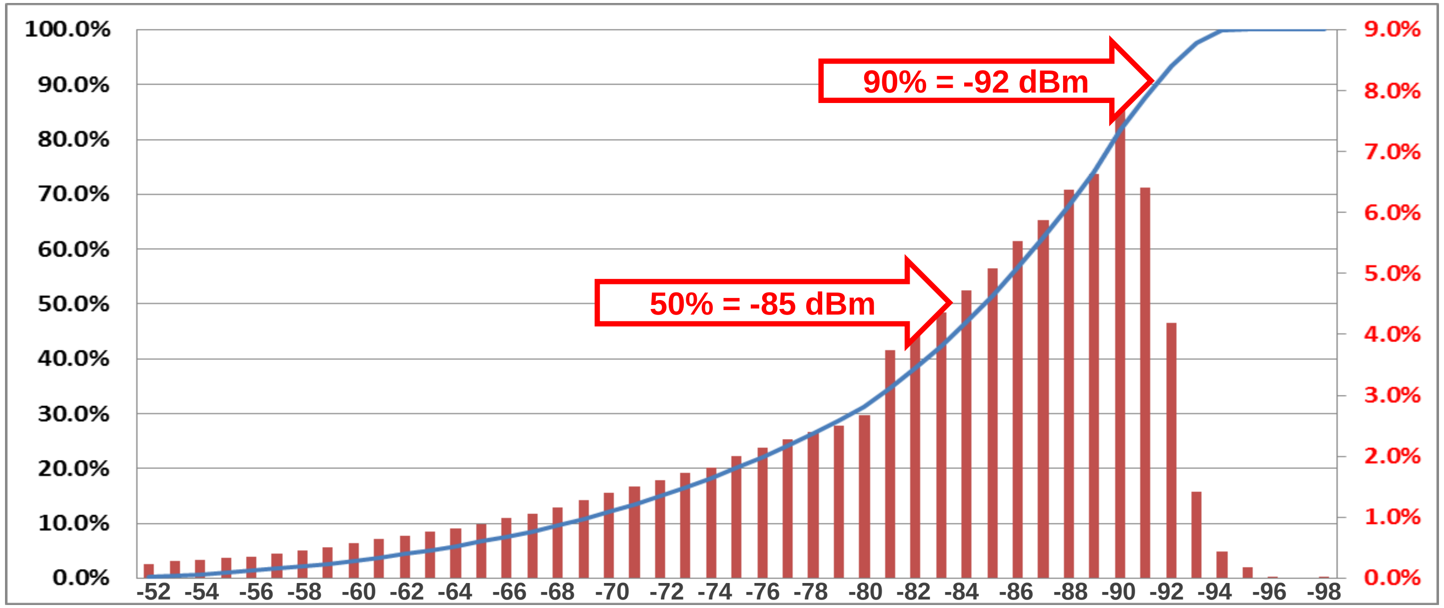
CableLabs UL RSSI Distribution

- CableLabs showed an UL RSSI Distribution of -52 to -94 dBm.
- Packets were shown as being received to cabled sensitivity which represents a "low cabled SINR" of 3 dB.



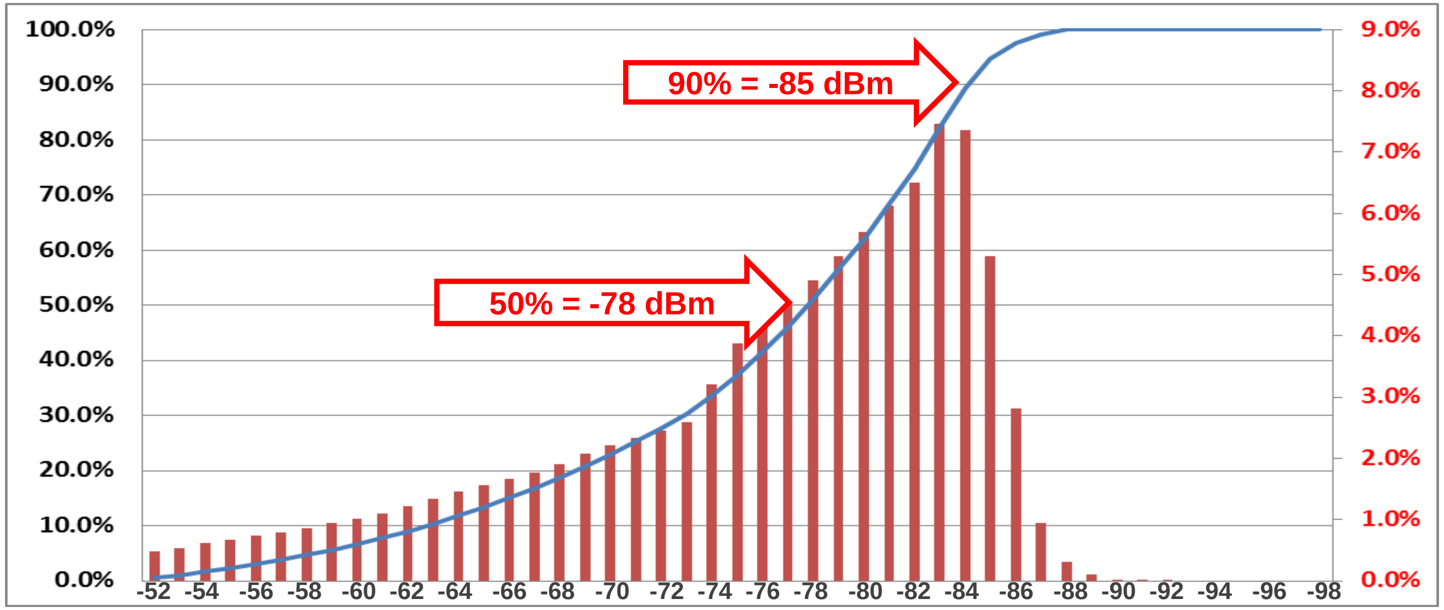
Analyzing the Distribution

- Looking at the data:
  - The 50th percentile of this distribution was -85 dBm.
  - The 90th percentile of this distribution was -92 dBm.



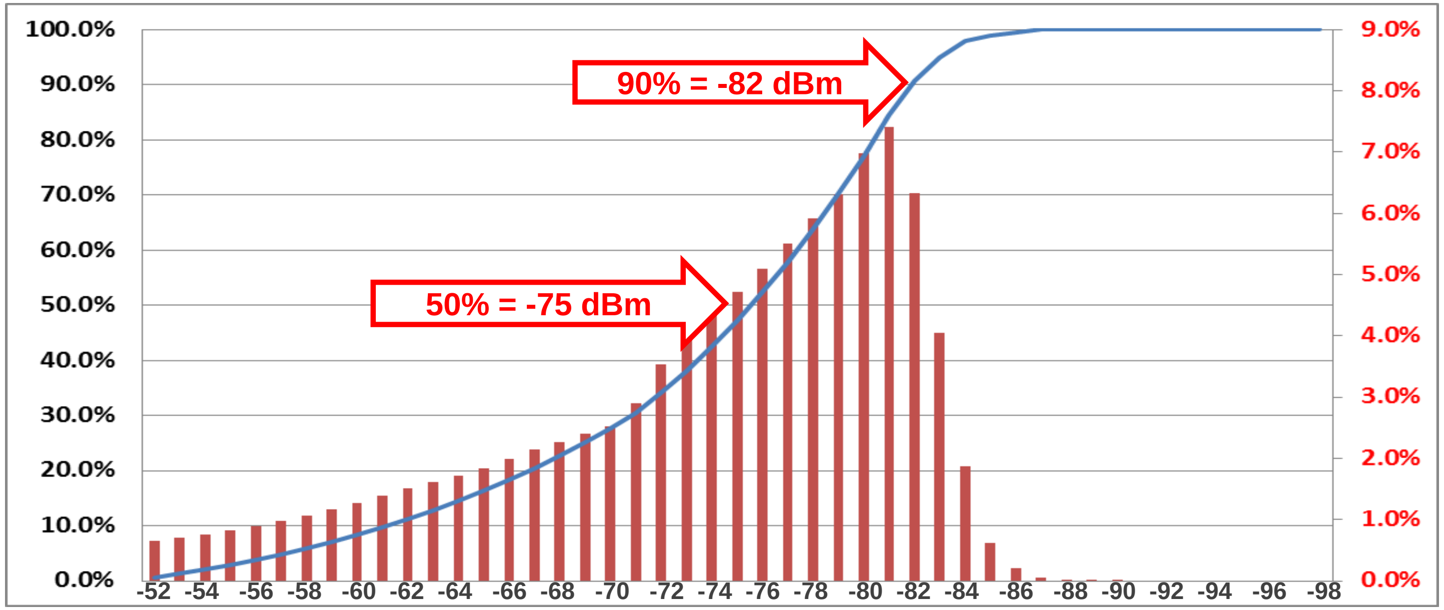
Accounting for CableLabs NF

- The previous numbers represent SINR, and must be adjusted to include the measured noise floor values.
  - The 50th percentile of this distribution becomes -78 dBm.
  - The 90th percentile of this distribution becomes -85 dBm.



Including 5 dB of NF Variability

- We showed that Noise Floor variability (i.e. interference) affects the RSSI reading Adjusting a minimal 5 dB of interference, we see:
  - The 50th percentile of this distribution was -75 dBm
  - The 90th percential of this distribution was -82 dBm
- These numbers are best case "guestimates" and unreliable



Summary

- CableLabs field data are relative measurements
- The data represents SINR – i.e. signal quality, and is not intended to be used as absolute RSSI numbers
- A best case "guestimate" shows a 10 dB error in the presented "absolute RSSI" values, however, this guestimate makes many assumptions about interference, and calibration
- None of the APs in the field have RSSI factory calibrated. It is not required by the IEEE, nor by the WFA. RSSI is a relative measure

- CableLabs data cannot be used to draw conclusions about absolute dBm values, and therefore, cannot be used to define an ED Threshold